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by

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SATELLITE POSITIONING SYSTEM AND FLIGHT DYNAMICS

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Abstract The development and application of satellite global positioning system (GPS) have been introduced in this paper, with the focus on the relation of GPS with flight dynamics. In GPS constellation configuration, ground station and user equipments, flight dynamics and its related discipline play an important role, become a part of the new developing subject. At last, some topics on advanced application of GPS related with flight dynamics are put forward.

Key words Satellite positioning system GPS application Flight dynamics

I. Development and Applications of GPS

The satellite positioning system is one of the major achievements in science and technology at present. From the launch of the first artificial satellite to the project proposal of the first generation satellite positioning system Transit, it was only one year. However, even before completion of the layout of the second-generation satellite positioning system GPS, the technology has been infiltrated into many fields of application in the military and civilian sectors, with many functions exploited in the Gulf War [1]. This extraordinary development

explains the urgency of society's requirements. At present, there have been continuously explored on the range of depth of GPS applications [2] and the indirect applications of many GPS combined and hybrid systems.

One of the major GPS users in global air route navigation of airliners, terminal and nonprecise entering the air space of an airport, precise landings and takeoffs as well as ground control from airports. The International Civil Aviation Corporation has specified the execution goal and missions at different stages with preliminary achievements. In aerospace, GPS can provide integrated services, from launching, orbital flight, atmospheric reentry, and landing of a spacecraft, as well as orbital determination of satellites and space stations in intermediate and low orbits, in addition to satellite rendezvous and dockings. Since 1982, GPS positioning experiments were conducted by the United States on the Landsat satellite series, spacecraft and other space flight vehicles. In oceanic navigation, GPS has more than 100,000 navigation users, and is developing toward harbor traffic control, geophysical prospecting in oceans, positioning of maritime platforms, as well as establishment of navigation beacons and buoys. By using satellite positioning for long-term observations of a point, joint observation of multiple points, or follow-up treatment, centimeter-level observational accuracy can be attained, thus providing new observational means for the study of terrestrial dynamics, earth's crustal motions, rotation, polar shift of the earth, geodetic surveying, and seismic monitoring.

Positioning and navigation of various ground vehicles, including trains, are also within the wide realms of GPS application prospects. By coordinating GPS along with the techniques of digital maps, and terrain-matching, determination of the position of a moving vehicle can be used for train dispatching, vehicle monitoring, control, and command. As one of the most wide-ranging effects in the United States Defense Department, GPS has only part of its applications for civilian use mentioned above. Actually, from its birth to its entire development process, GPS has served the military, from the positioning of a single soldier to space defense, monitoring of nuclear explosions, and ground to outer space, GPS has been applied to various military branches, with good verification in the Gulf War.

The GPS is composed of three major components: space satellite network, ground control, as well as monitoring network and user equipment. Established on the space technical foundation by comprehending the most recent achievements of the present-day geodetic surveying, atmospheric surveying, high-frequency radio, digital communication, and computer techniques, GPS development and applications require multidisciplinary high-tech support. The article briefly describes the functions of flight dynamics on space constellation configuration, operations of surveying and control networks, and user equipment. In particular, some research topics are listed in the application of flight dynamics in high-level applications of GPS.

II. Problems of Flight Dynamics in the Space-Related Portion of GPS

The space network of GPS consists of 24 satellites distributed over six orbits. These satellites broadcast to users the brief but precision satellite orbital parameters, time parameters, atmospheric parameters, and other necessary updated parameters. Such GPS tasks as ephemeris computations, launch, as well determination and updating of orbits are established on the foundation of classical flight dynamics. In this article, the flight dynamic problems of carriers used for launching GPS satellites are not discussed.

By positioning objects near the earth's surface by satellite, first the properties of the earth's gravitational field should be correctly understood, including mass distribution in the earth, shape of sea levels, and reference ellipsoid, so that a coordinate system can be established adaptable to the entire globe with precision within certain limits. To satisfy the requirements of the Defense Department about the GPS project, in 1986 the Defense Mapping Agency of the United States announced a World Geodetic System, 1984 (WGS-84). The system provides a reference coordinate system by using the earth's center of mass as its origin, and an earth-bound reference coordinate system, defining of gravitational field model for the earth, geodetic water level, angular velocity of rotation, and the conversion relationship between the coordinate system and the other (more than 90) local coordinate systems, as the basis for the existence of GPS.

In the layout of the GPS satellite network, orbital dynamics is the most fundamental part of classical flight dynamics. By using Kepler's orbital law, we can determine the minimum number of satellites, and the satellite orbital parameters required for global coverage, as well as determination of the minimum orbital parameters that should be sent to the users in order to attain a precise ephemeris. With relative motion between the satellite motion and the users, and the analysis of relative geometric relationships, we can obtain the compensation on the satellite clock as affected by relativity theory, an estimate of atmospheric propagation effects, satellite feasibility analysis, and monitoring of completeness of the space satellite network. We can say that flight dynamics is the support for the development of GPS space activities. By analyzing the GPS constellations, not only can users better utilize GPS, but also the combined functions of developing China's satellite system, with respect to GPS/GLONASS (Global Navigation Satellite System of the former Soviet Union). It is also very important to share resources between GPS and other satellite system, such as the International Maritime Satellite.

III. Flight Dynamics Problems in the Monitoring Part of GPS

The monitoring part of GPS is composed of a main control station, an input station, and several monitoring and control stations. They have the following tasks: collecting local atmospheric data, to propose a third-order polynomial system

based on the ionospheric broadcasting error model and the tropospheric broadcasting error model, to be sent to GPS satellites for user applications. Likewise precise observation of GPS orbits ensures user convenience by application of simple models for orbital precision within a short period. The necessary updating computations can be done on GPS time in the satellites. With computations on the effect of relativity theory, clock instability and clock asynchronism, the compensation parameters can be determined.

Observation of satellite orbits is a typical problem in flight dynamics. In the early 17th century, the famous astronomical physicist, Kepler, announced three major laws of planetary motion to quantitatively describe the planetary orbits and motion laws. In Newton's famous work, Mathematical Principles of Natural Philosophy, in 1687, he displayed the law of universal motion, thus changing the concept and customs of the entire world. In the succeeding more than three centuries, several famous mathematicians and mechanicists, such as Halley, Euler, Lambert, and Gauss, made important contributions to precise orbital determinations. The development of modern science and technology not only makes more precise constellation observations, but also makes it possible for launch and applications of artificial satellites. Except for reliance on the fundamental principles of mechanics laid down by previous researchers, important functions are provided by various tracking methods, such as radar, optics, radio interference, radio

emission, and astronomy, in addition to large computers and various data processing methods.

Other than the function of the earth's gravitational attraction for the actual satellite orbit, the orbit is also affected by the earth's irregular shape, nonuniform distribution of the earth's mass, tidal phenomena, gravitational attraction by the sun and moon, pressure of light from the sun, atmospheric resistance, and meteor perturbation. After determining the precise positions of a satellite, use a simple model and a smaller number of parameters for matching in a certain time domain, for real time use by users. All these tasks are accomplished by the ground main control station.

IV. Flight-Dynamic Problems with Respect to Users

GPS user equipment receives satellite signals, then the position, velocity, and time information are derived after the signals are properly processed. In the information, the knowledge of flight dynamics and its related discipline is the foundation of mechanical arrangement and software algorithm for positioning.

4.1. Transformation of Coordinate Systems

Due to different research problems, the variables in different coordinate systems have different definitions. To process these variables in other coordinate systems, coordinate transformation is often employed. For example, when a satellite

moves in its orbital plane, for sake of convenience, first the satellite position should be determined by using the principal axis of the orbital ellipse. Next, by using the orbital dip angle and the longitude of the ascending node, the satellite's position in the rectangular coordinate axis system (such as WGS-84) of the earth's center can be determined. Based on application requirements, the position can be expressed in the geographical coordinate system, plane coordinate system, and the relative coordinate system, after transformation. Refer to reference [3] for definition and intertransformation of various coordinate systems.

4.2. Optimal Selection of Satellites

Different satellite distributions have different positioning effect on users. To upgrade the positioning precision, we must select the four optimal operating satellites from all visible satellites. By using the analysis of the relative positions between the user and the GPS satellites, and the covariance analysis of pseudo-distance measurements, the standard of optimal satellite selection can be determined by applying the principle of the minimum positioning error.

4.3. Satellite Position Forecasting

Users must be aware of the distribution of all satellites in the GPS constellation for timely change of the operating satellites to shorten the acquisition time, all satellite

calendars (brief ephemerides) are found in the telegram file of each satellite. By using general formulas of the orbital dynamics, a user can forecast the general position of a satellite.

4.4. Hybrid Navigation Guidance

To make up for the shortcomings of GPS in expanding the range of applications, for higher precision and reliability, generally the GPS is used with other navigation guidance equipment or methods. For example, in the case of the combination of GPS/INS or GPS/Doppler, the dynamic requirements of the flight vehicle can be satisfied, in addition to upgrading the data output rate and precision, GPS/terrain-matching or GPS/digital map may be employed. These techniques can be used in precise guidance of aircraft and missiles. The combination of GPS and starlight navigation guidance can be used for spacecraft guidance. In the case of the combination of GPS/navigational position, short-term loss of satellite signals can be made up for. These hybrid systems require the establishment of error models for coordinate transformation, processing of navigation guidance information, and design of Kalman filters, among other means.

4.5. Flight Vehicle Dynamics

As a sensitive element for positioning, velocity determination, and timing of flight vehicles, sectors of guidance

circuits of the GPS should be considered. By paying attention to lag phenomena in GPS as to dynamic positioning, effects will be encountered with respect to satellite window, locking phase ring, and quartz clock of the GPS in a highly mobile environment. The interaction of this flight vehicle dynamics and GPS receivers should be considered by the dynamics users.

V. Advanced Research Subjects of Flight Dynamics in GPS Applications

Notwithstanding the fact that GPS has been successfully applied in many fields, however the application range and depth are still expanding. In other than direct applications of GPS, we call these applications as advanced applications, such as, via other systems, other equipment, other technical combinations, hybridization, or expansion of the original design in the range of applications, environment, and controlled systems, or with secondary development. At present, there are the following oft-discussed subjects based on flight dynamics:

a. Research on space application environment: by using GPS in a spacecraft (ballistic guided missile, aerospace plane, flight ship, and satellites), the originally designed application environments are modified. This requires the establishment of compensatory models on various error sources, constellation layout, and feasibility analysis.

b. Application and research in highly mobile environments:

there are major developments at present, such as the development of novel, highly mobile receivers, external information supplement that can be used, variable-structure Kalman filtration, and use of software for estimation of dynamic behaviors.

c. Redundancy system of multiple sensors: by using a combination of two or more systems, including GPS, to provide redundant information, this approach can monitor and isolate malfunctions for complete monitoring, and sharing of supplementary information among systems.

d. Research on hybrid systems: here the subject includes the above-mentioned hybrid systems. However, a combination of subsystems can be operated in series or in parallel. In the research content, there is compatibility between hybrid systems, reconnection dynamics, and error transfer, among other subjects.

e. Phase measurement technique: by using the GPS phase measurement technique, higher precision can be obtained. This has mature results in geodetic surveying, with the development at present towards dynamic positioning.

f. Attitude fixation: by using the precise relative positioning technique, attitude angles of a carrier can be measured. This technique has attained higher precision for a

long baseline, such as a ship. One of the important GPS research areas is attitude surveying of flight vehicles.

g. Effects of earth's rotation: earth's rotation will induce the effects of relativity theory as regards to satellite time, thus affecting the results that the WGS-84 coordinate axis system is bound to earth as an inertial system for consideration in precise positioning.

h. Research on the difference technique: at present, it is known that the difference technique can greatly upgrade positioning accuracy. However, specify only a uniform difference format in oceanic navigation, such as research on various difference methods (such as pseudo-distance difference, positional difference, phase difference, multiple difference, and relative difference), the design of difference stations, and research on wide-domain difference, in particular, the difference technique used in aviation, in mobile reference stations, and in application research. These techniques are within the large area research realms under study in various countries.

i. Completeness monitoring: completeness monitoring is one of the important topics in GPS applications. This can be considered in the entire system and also can be solved from the redundant user information. Beginning with the dynamic analysis of flight vehicles, flight dynamics utilizes the relationship

between sensor information and dynamics to solve the completeness monitoring problem of users.

VI. Conclusions

As a new technical achievement, GPS is a multidisciplinary product. However, from the GPS satellite network layout to the ground control network and the operation of user equipment, from the most fundamental definition of the GPS system to its application in various levels, flight dynamics has infiltrated into all processes. Flight dynamics acts as the foundation and supporting columns for GPS development and applications; however, GPS also has new contents for flight dynamics, in promoting further development of the discipline of flight dynamics. Therefore, flight dynamics researchers should confront the major front of economic construction to put forth more effort in more extensive and higher levels of GPS applications.

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